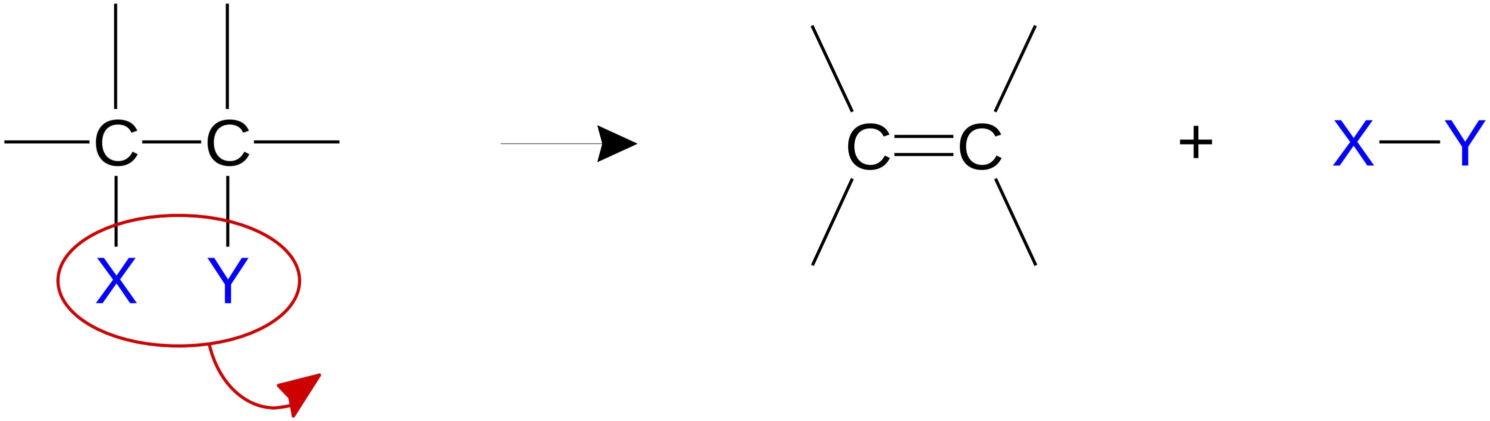
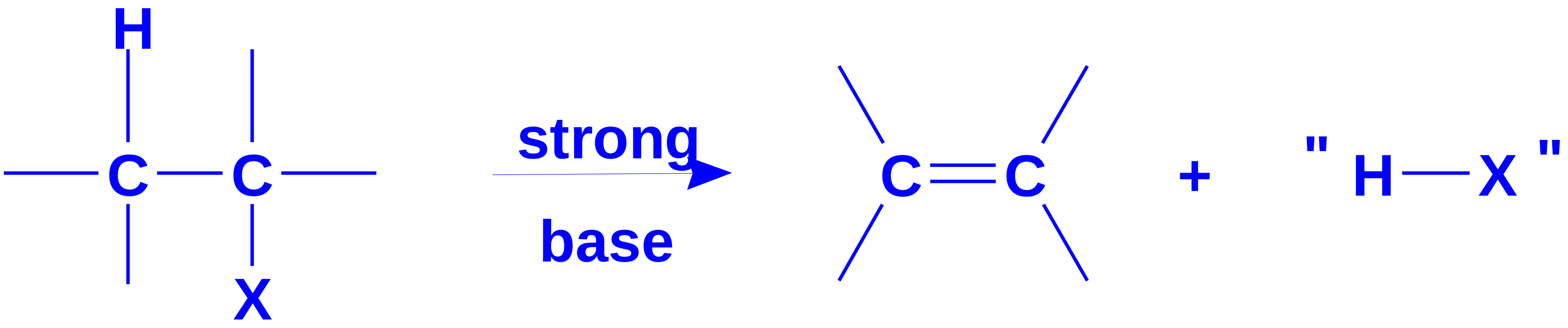
Sect. 9.2 Elimination Reactions

Dehydrohalogenation (-HX) and Dehydration (-H_2O) are the main types of elimination reactions.



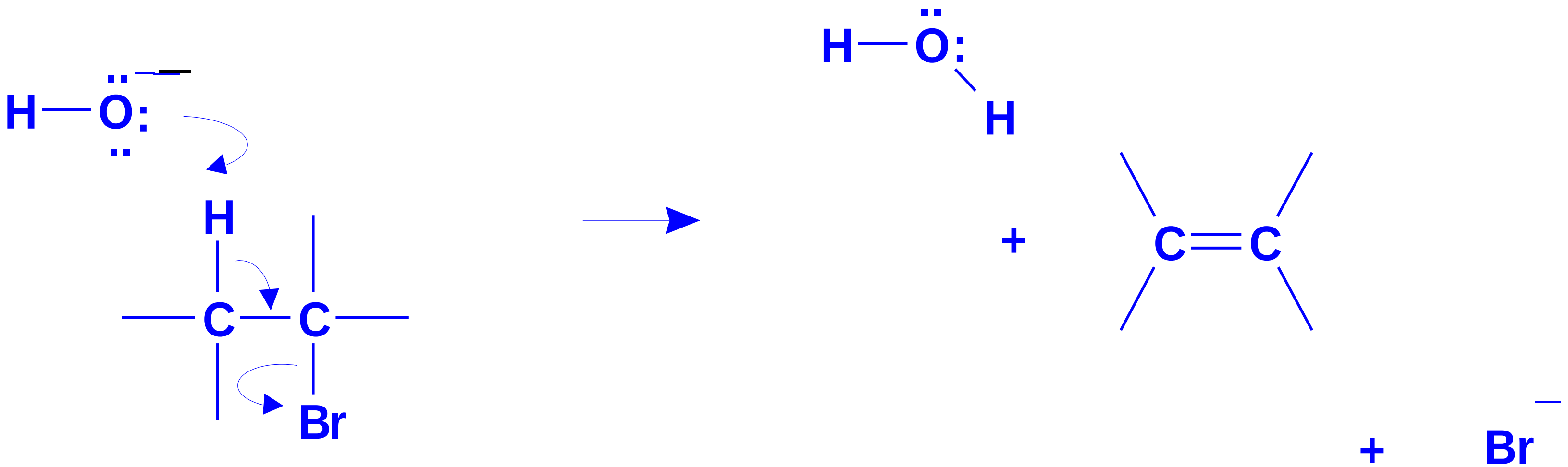
Dehydrohalogenation (-HX)



X = Cl, Br, I

Sect 9.3: the E2 mechanism

This reaction is done in *strong base at high concentration, such as 1 M NaOH in water.*



concerted mechanism

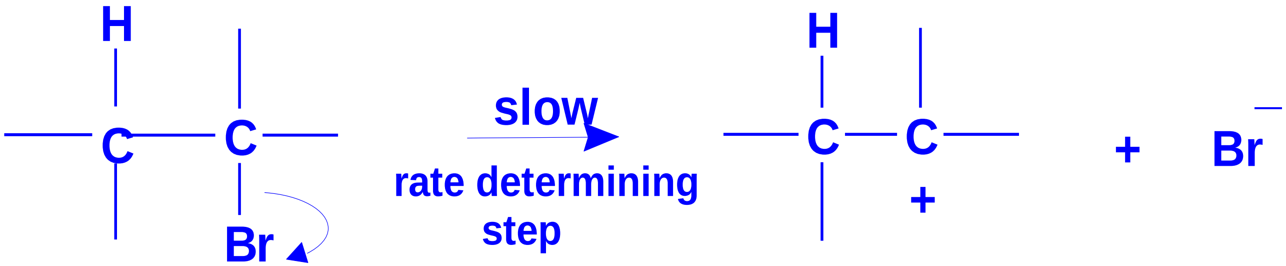
Kinetics

- The reaction in strong base at high concentration is second order (bimolecular):
- Rate law: rate = $k[OH^-]^1[R\text{-}Br]^1$

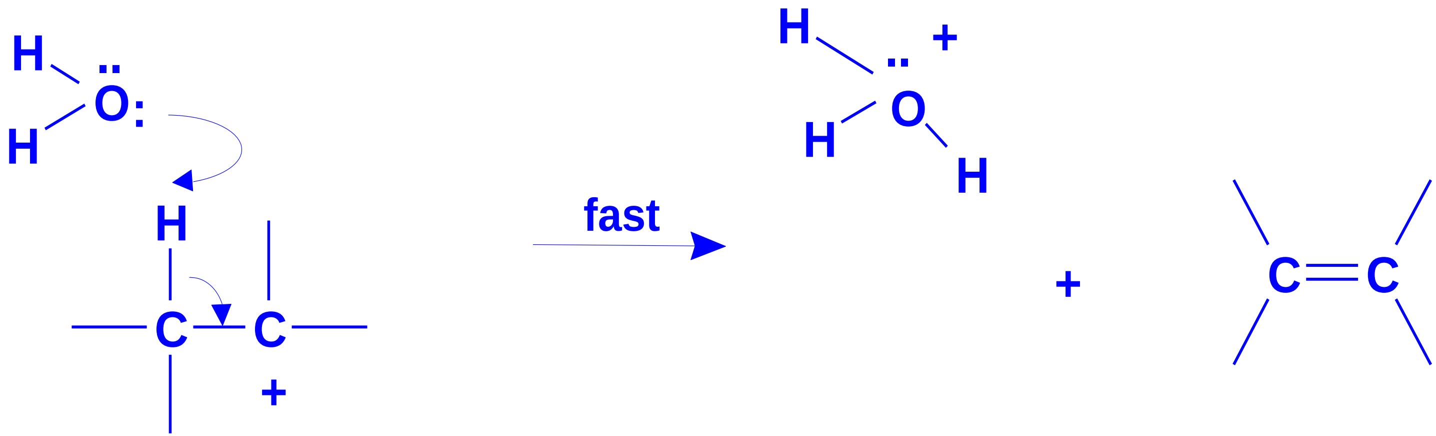
Sect 9.3: the E1 mechanism

This reaction is done in *strong base such as 0.01 M NaOH in water!! Actually, the base solution is weak!*

1)



2)



Kinetics

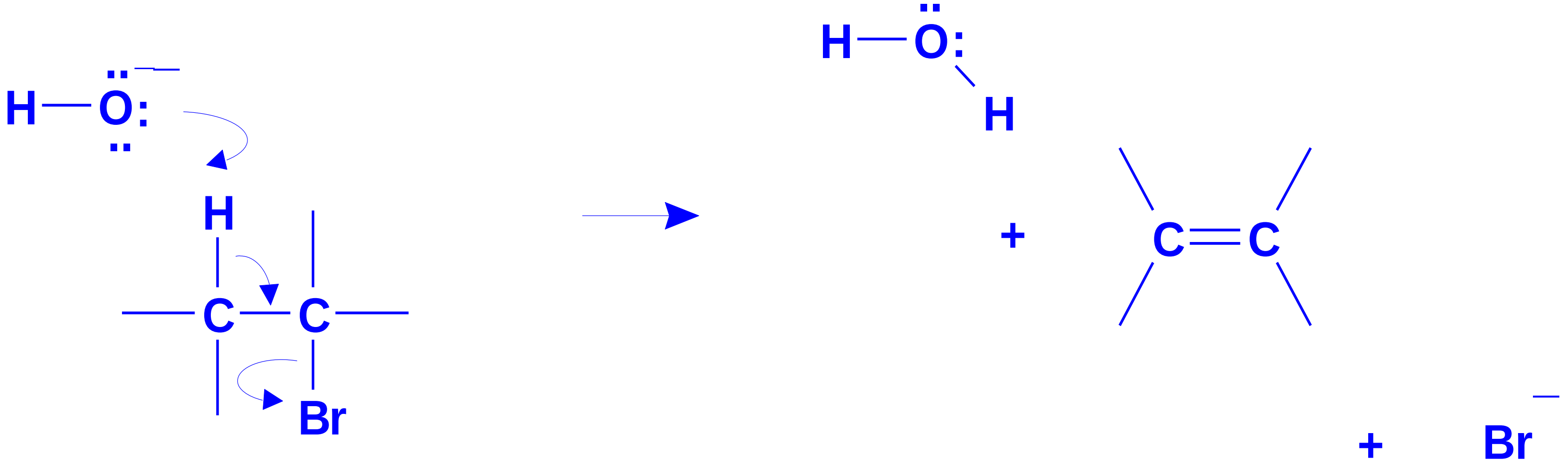
- The reaction in weak base or under neutral conditions will be first order (unimolecular):
- Rate law: rate = k $[R\text{-}Br]^1$
- The first step (slow step) is rate determining!

Sect 9.4: the E2 mechanism

- mechanism
- kinetics
- isotope effects
- stereochemistry of reactants
- orientation of elimination (Zaitsev’s rule)
- stereochemistry of products
- competing reactions

E2 mechanism

This reaction is done in *strong base at high concentration, such as 1 M NaOH in water.*



concerted mechanism

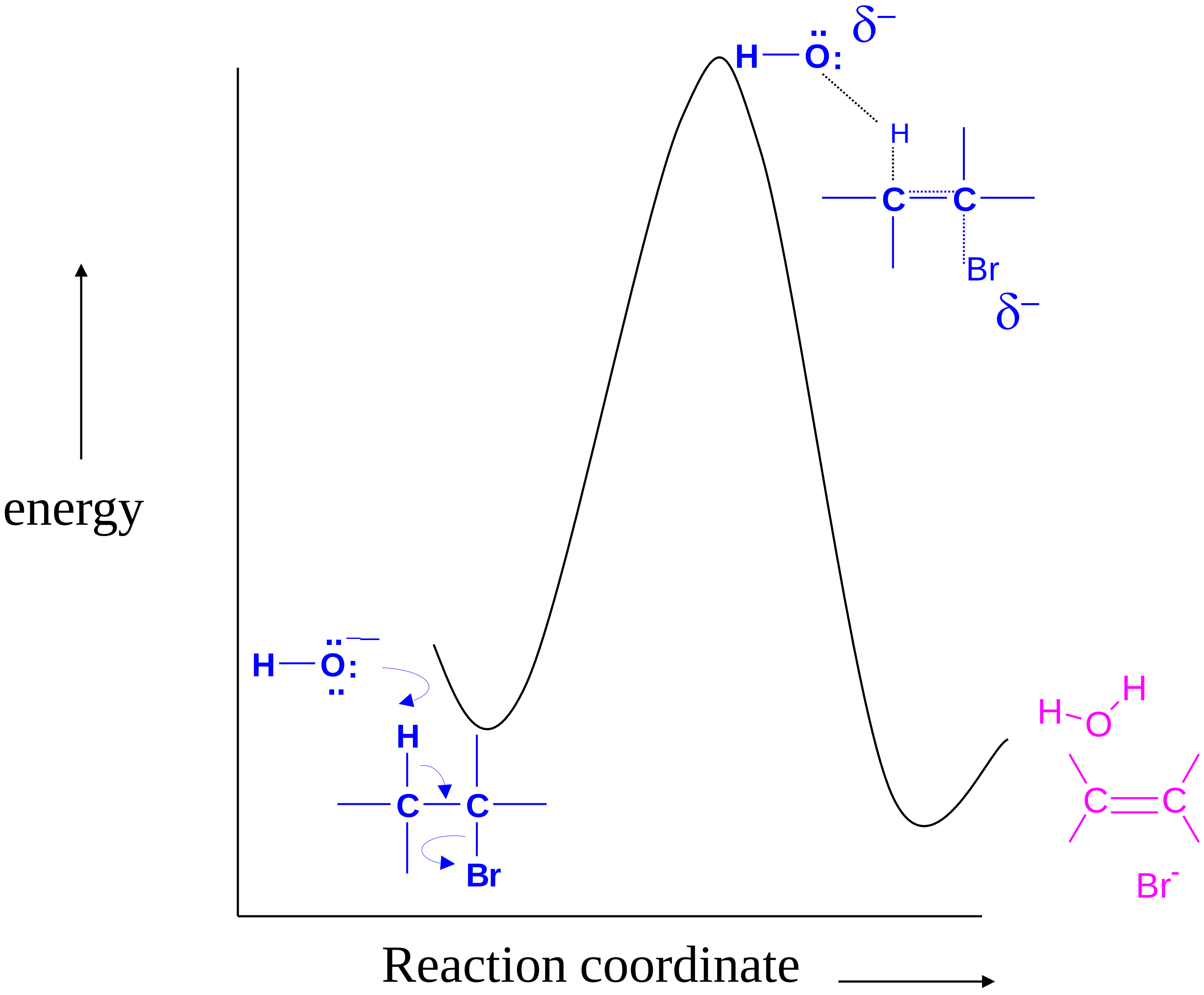
Kinetics of an E2 reaction

- The reactions are second order (bimolecular reactions).

- Rate = k $[\text{R-Br}]^1[\text{Base}]^1$

  second order reaction (1 + 1 = 2)

  High powered math!!


energy
H—Ö:⁻
H
C—C
Br
H—Ö:
δ−
H
C—C
Br
δ−
H
H
O
C═C
Br-
Reaction coordinate

Isotope Effects

- Change in rate brought about by replacing an hydrogen atom by its isotope, deuterium.

  C-D bond is stronger than a C-H bond!

- Usually expressed as

  $$k_H/k_D$$

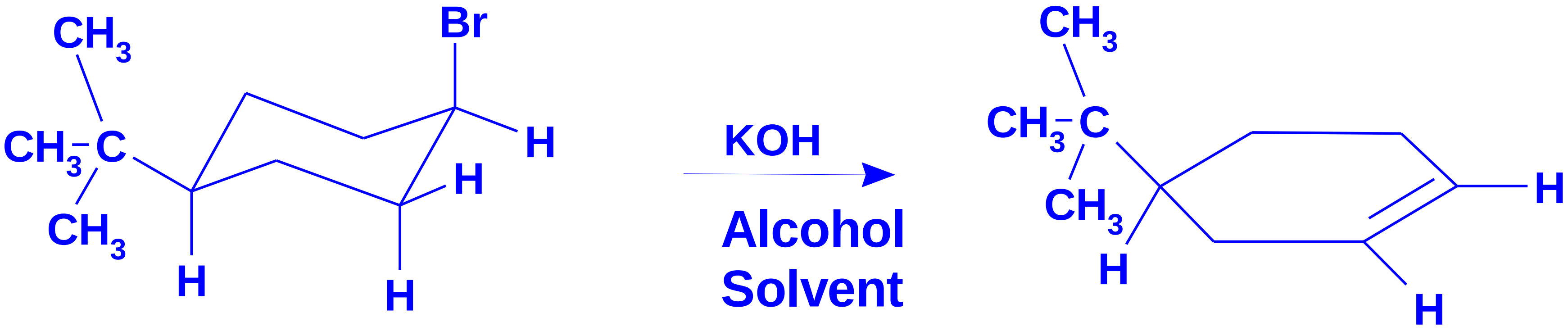
- If k_H/k_D = about 7.0, this means that the isotopically-labeled bond is being broken in the rate-determining step, indicating that the reaction is E2.

Stereochemistry of reactants

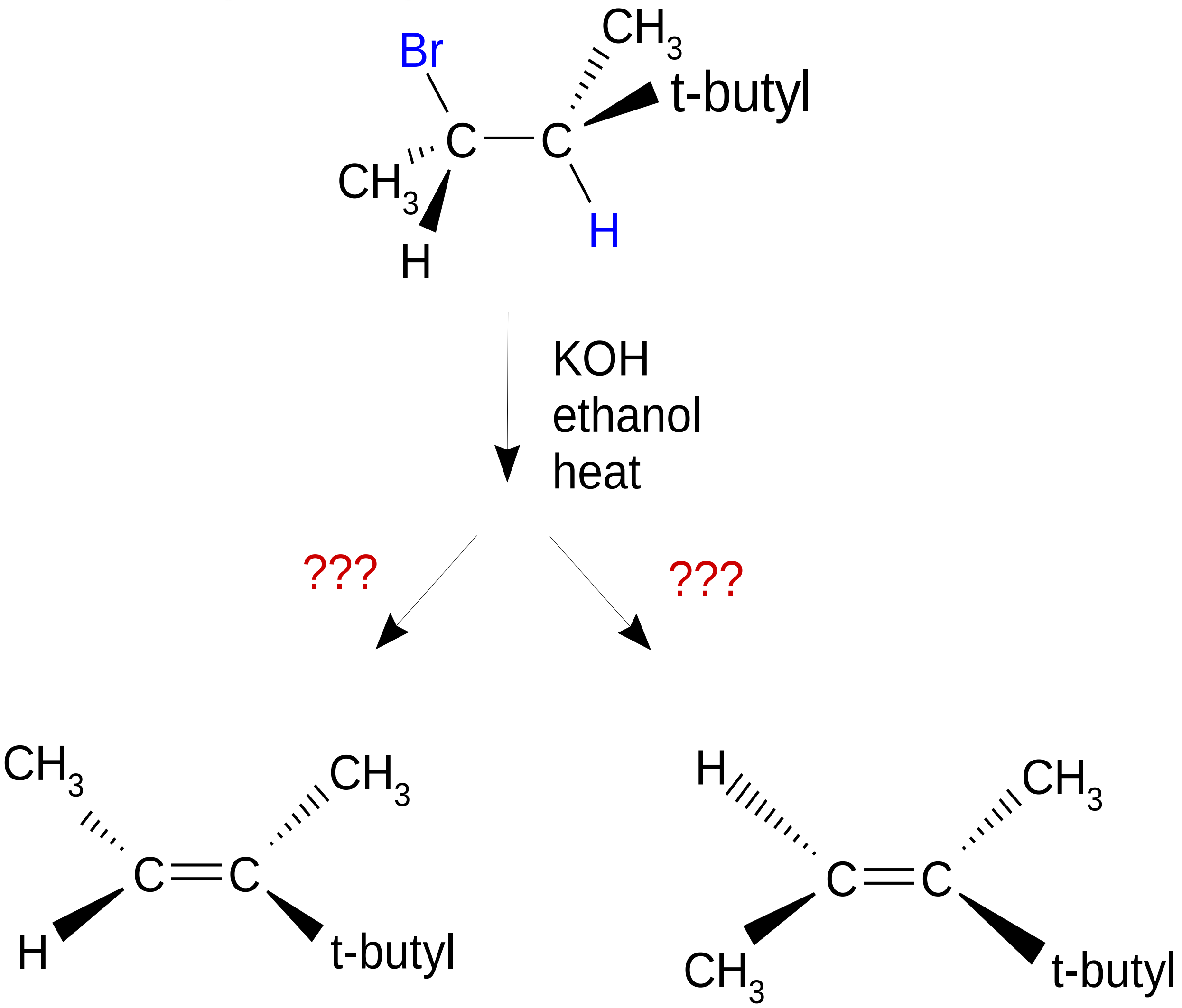
- E2 reactions must go by an *anti elimination*
- This means that the hydrogen atom and halogen atom must be 180^o (*coplanar*) with respect to each other!!
- Draw a Newman projection formula and place the H and X on opposite sides.

Stereochemistry of E2 Reaction

This is the *cis* isomer. The *trans* isomer does not react by an E2 reaction.



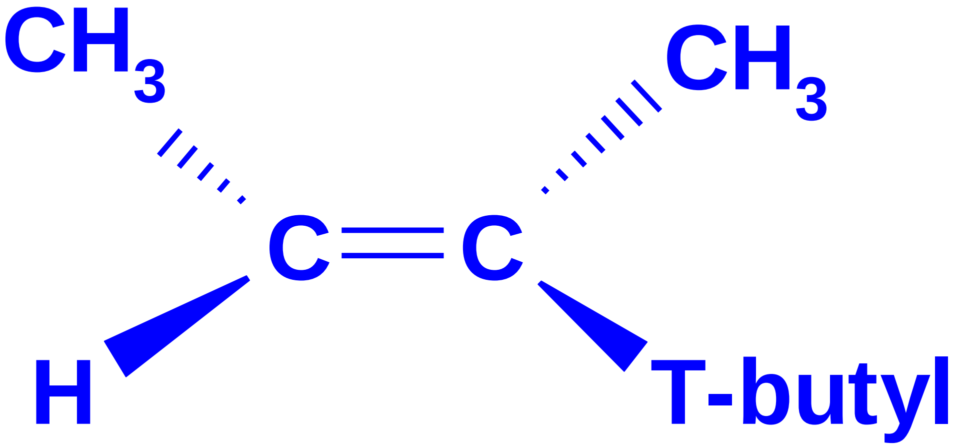
(S,S)-diastereomer



(E)-isomer

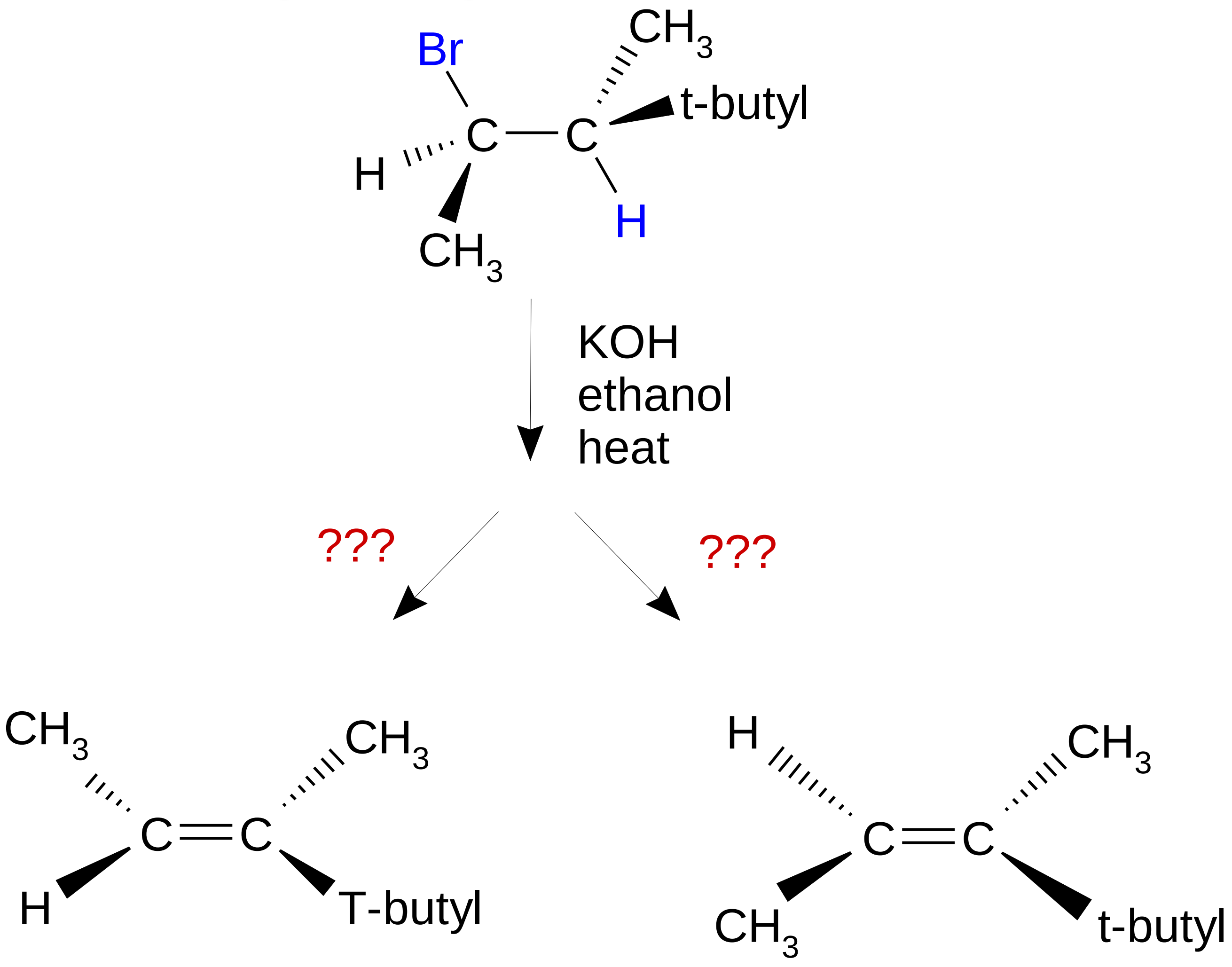
(Z)-isomer

This one is formed!



(E)-isomer

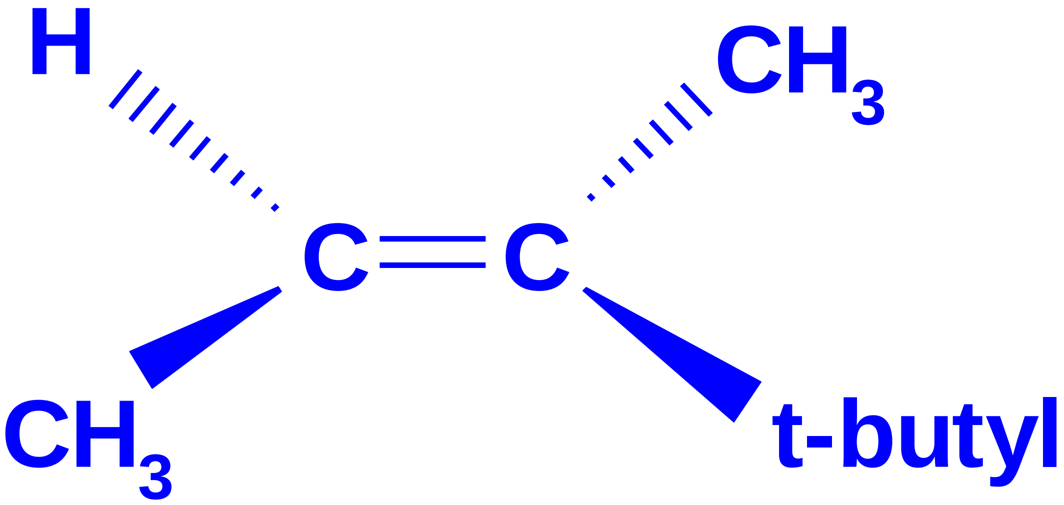
(R,S)-diastereomer



(E)-isomer

(Z)-isomer

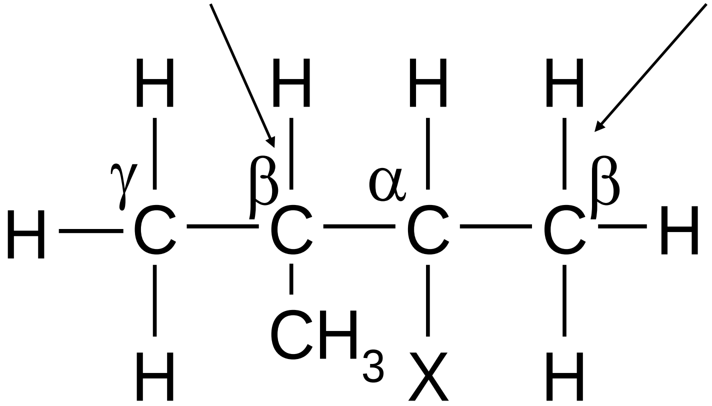
This one is formed!



(Z)-isomer

Orientation of elimination: regiochemistry/ Zaitsev’s Rule

- In reactions of removal of hydrogen halides from alkyl halides or the removal of water from alcohols, the *hydrogen* which is lost will come from the *more highly-branched* β-carbon.



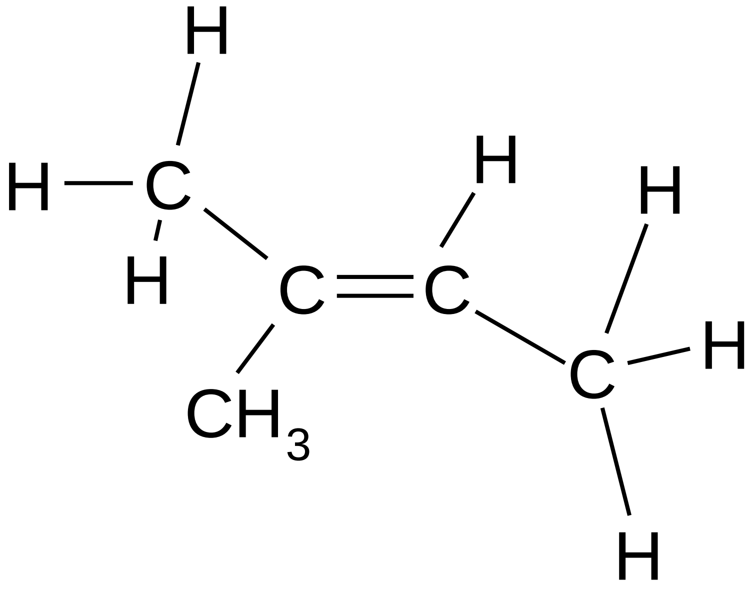
$$CH_3-CH(CH_3)-CHX-CH_3$$

More branched

Less branched

A. N. Zaitsev -- 1875

Product formed from previous slide



Typical bases used in E2 reactions

High concentration of the following >1M

If the concentration isn't given, assume that it is high concentration!

- $Na^+ \ ^-OH$
- $K^+ \ ^-OH$
- $Na^+ \ ^-OR$
- $Na^+ \ ^-NH_2$

Orientation of elimination: regiochemistry/ Zaitsev's Rule

Explaination of Zaitsev's rule:

When you remove a hydrogen atom from the more branched position, you are forming a more highly substituted alkene.

Stereochemistry of products

- The H and X must be *anti* with respect to each other in an E2 reaction!
- You take what you get, especially with diastereomers! See the previous slides of the reaction of diastereomers.

Competing reactions

- The substitution reaction (S_N2) competes with the elimination reaction (E2).
- Both reactions follow second order kinetics!

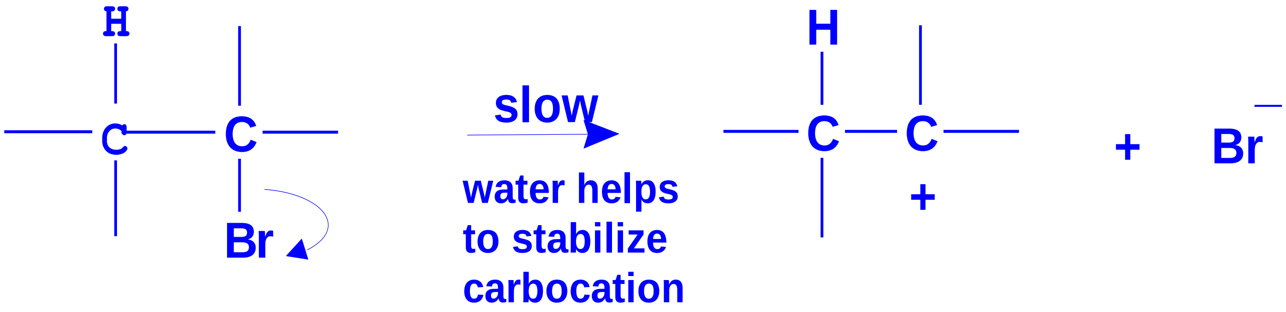
Sect 9.5: the E1 mechanism

- mechanism
- kinetics
- isotope effects
- stereochemistry of reactants
- orientation of elimination (Zaitsev’s rule)
- stereochemistry of products
- competing reactions

E1 mechanism

This reaction is done in strong base at low concentration, such as *0.01 M NaOH in water)*

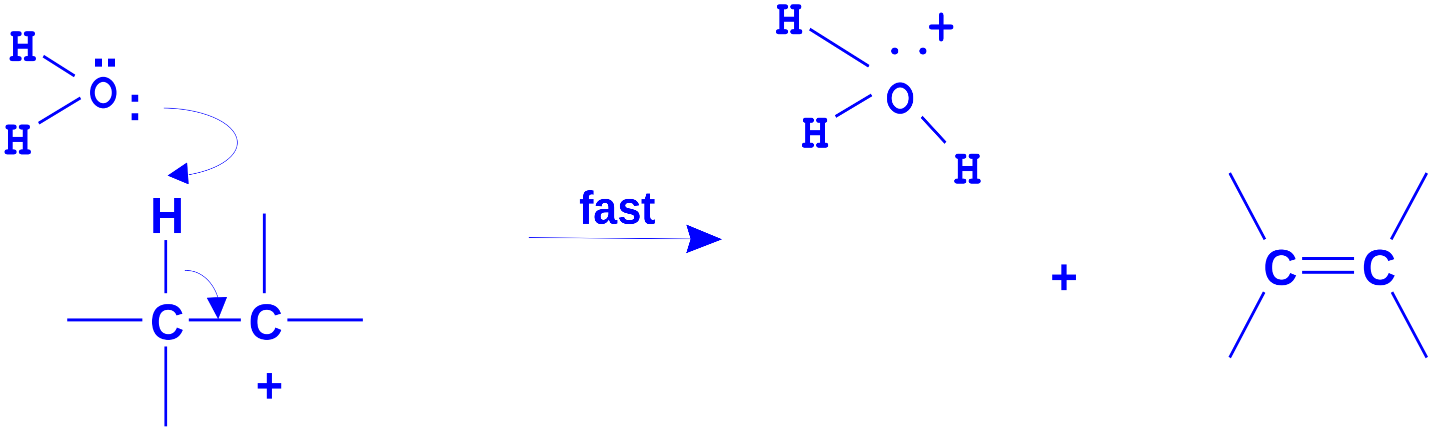
1)



slow

water helps to stabilize carbocation

2)



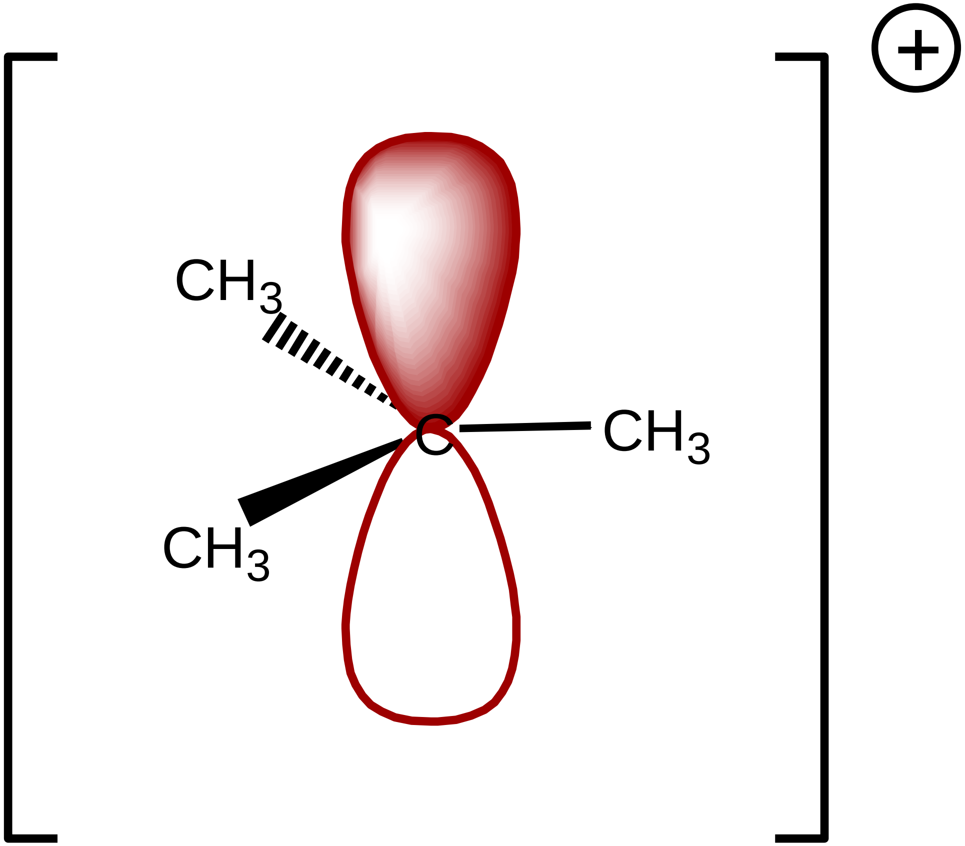
fast

E1 Reactions

- These reactions proceed under neutral conditions where a ***polar*** solvent helps to stabilize the carbocation intermediate.
- This solvent also acts as a weak base and removes a proton in the fast step.
- These types of reactions are referred to as ***solvolysis*** reactions.

- tertiary substrates go by E1 in polar solvents, with little or no base present!
- typical polar solvents are water, ethanol, methanol and acetic acid
- These *polar* solvents help stabilize carbocations
- E1 reactions also occur in a low concentration of base (i.e. 0.01M NaOH).

Structure of the Carbocation Intermediate



Carbocation stability order

Tertiary (3^o) > secondary (2^o) > primary (1^o)

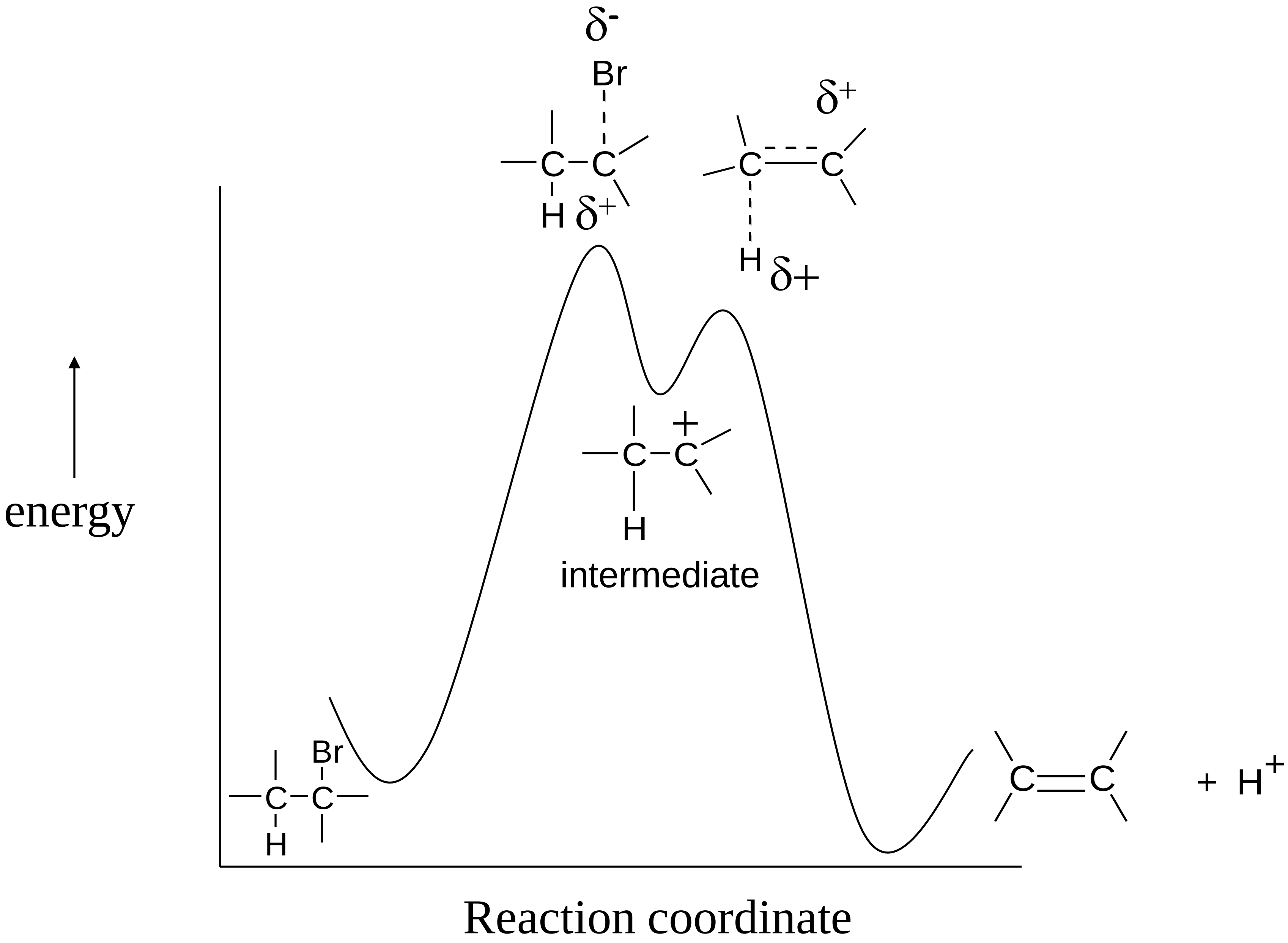
It is hard (but not impossible) to get primary compounds to go by E1. The reason for this is that primary carbocations are not stable!

Kinetics of an E1 reaction

- E1 reactions follow first order (unimolecular) kinetics:

  Rate = k $[R\text{-}X]^1$

  The solvent helps to stabilize the carbocation, but it doesn't appear in the rate law!!

δ-
Br
C–C
H δ+
δ+
C–C
H δ+
energy
+
C–C
H
intermediate
Br
C–C
H
C=C
+ H+
Reaction coordinate

Isotope effects

- E1 reactions do not show an isotope effect:

  $k_H/k_D = 1$

- This tells us that the C-D or C-H bonds are not broken in the rate determining step (step 1). They are broken in the fast step (step 2) in the mechanism.

Stereochemistry of the reactants

- E1 reactions do not require an *anti coplanar* orientation of H and X.
- Diastereomers give the same products with E1 reactions, including *cis*- and *trans* products.
- Remember, E2 reactions usually give different products with diastereomers.

Orientation of elimination

- E1 reactions faithfully follow Zaitsev's rule!
- This means that the major product should be the product that is the most highly substituted.

Stereochemistry of products

E1 reactions usually give the thermodynamically most stable product as the major product. This usually means that the largest groups should be on opposite sides of the double bond. Usually this means that the *trans* product is obtained.

Some examples of E1 and E2 reactions

Competing reactions

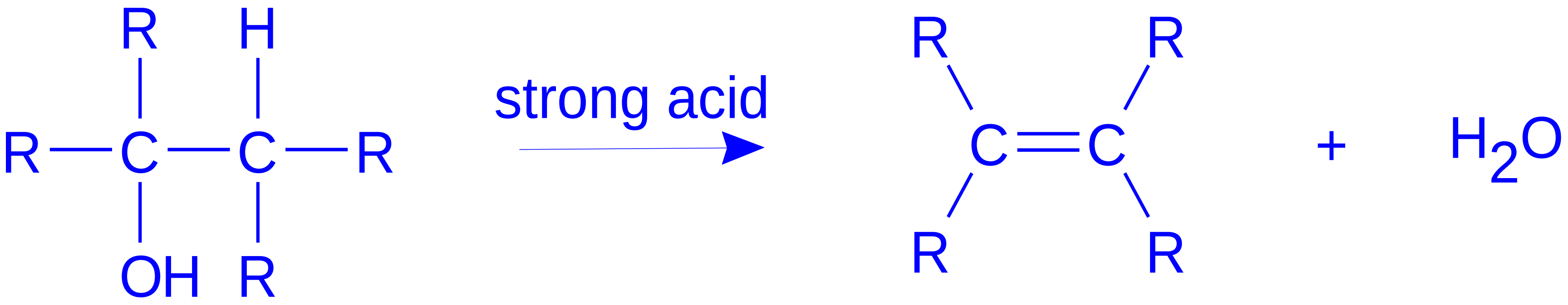
- The substitution reaction (S_N1) competes with the elimination reaction (E1).
- Both reactions follow first order kinetics!

Whenever there are carbocations…

- They can undergo elimination (E1)
- They can undergo substitution (S_N1)
- They can rearrange
  - and then undergo elimination
  - or substituion

Sect 9.6: Dehydration of Alcohols (acid assisted E1)

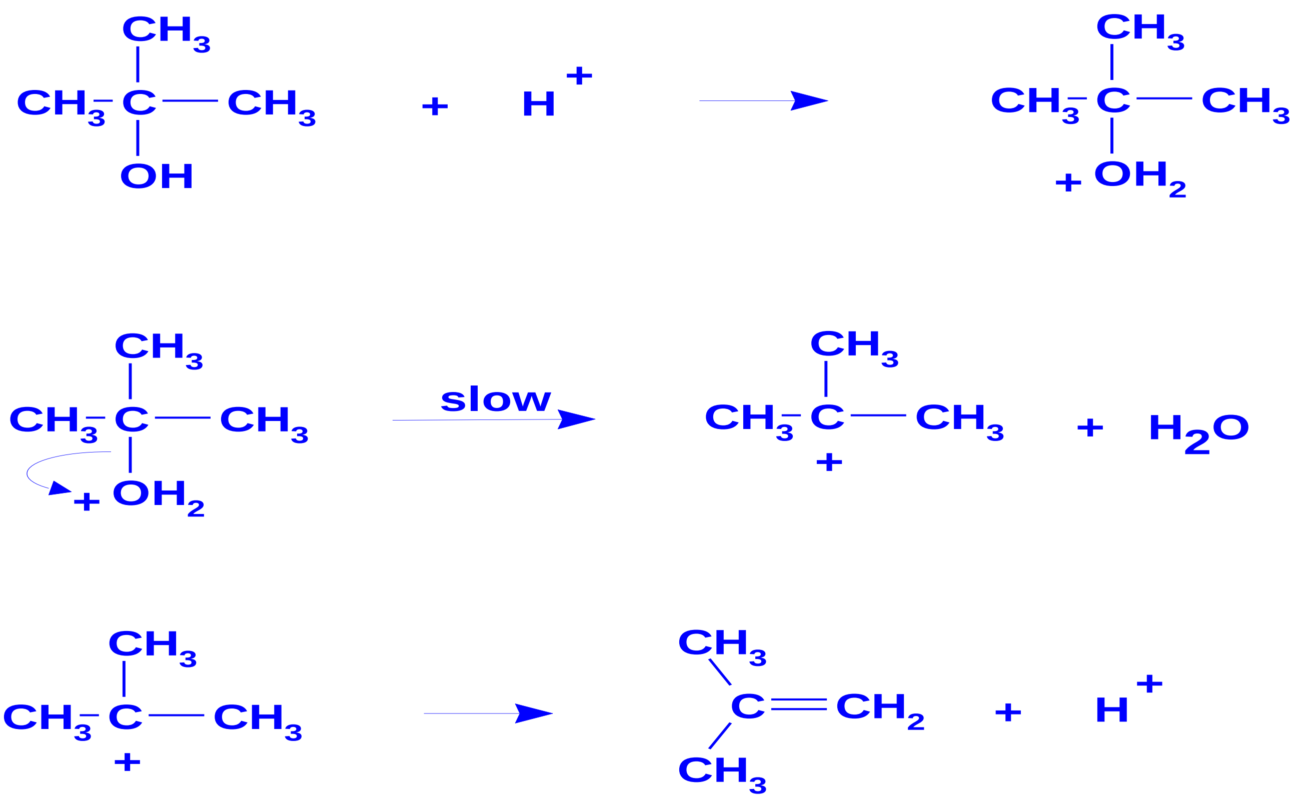
Acid assisted reactions are always E1



Which strong acids are used?

- H_2SO_4
- H_3PO_4

Mechanism of Dehydration

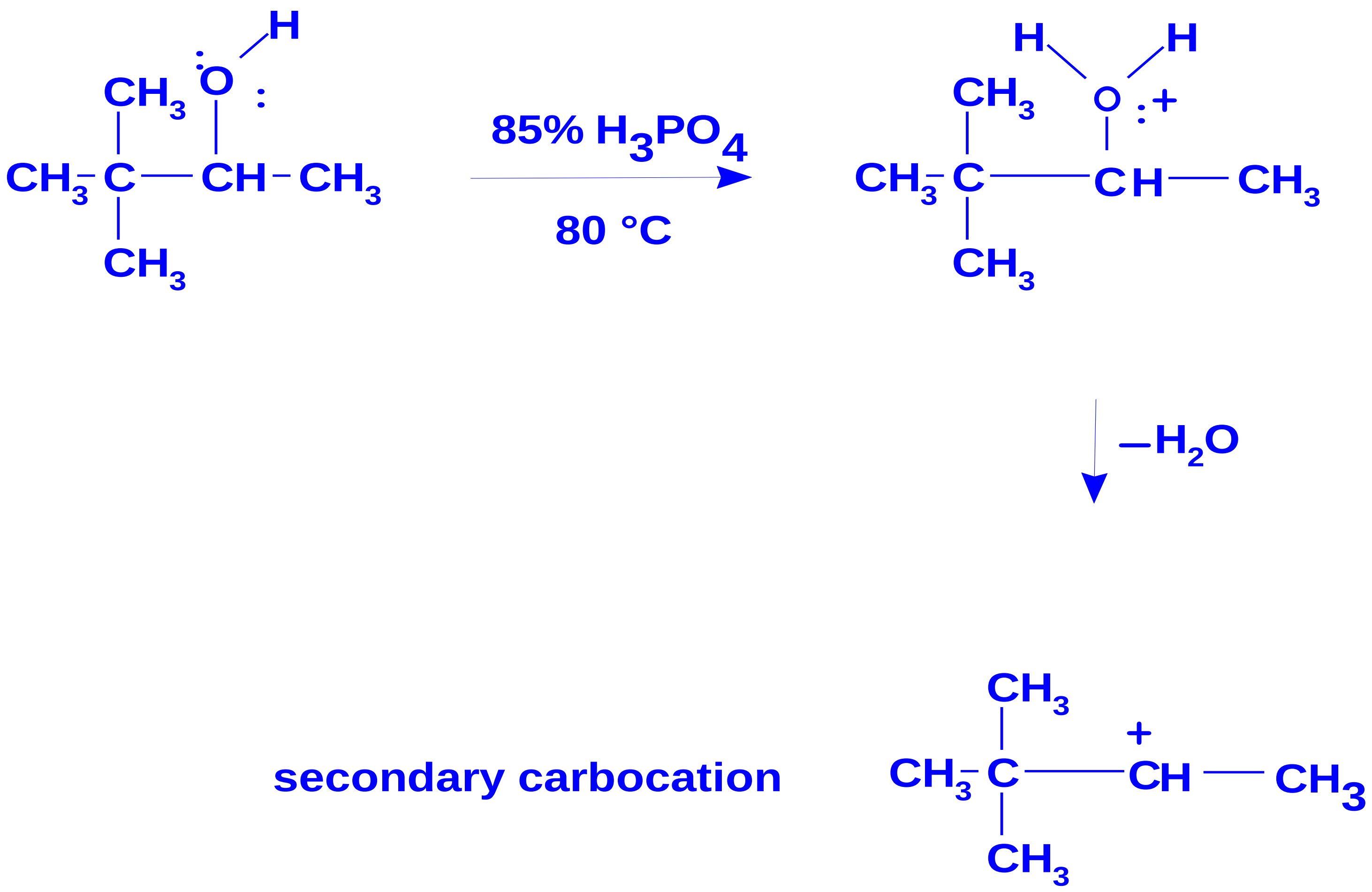


1) $$CH_3-\underset{OH}{\overset{CH_3}{C}}-CH_3 + H^+ \longrightarrow CH_3-\underset{+OH_2}{\overset{CH_3}{C}}-CH_3$$

2) $$CH_3-\underset{+OH_2}{\overset{CH_3}{C}}-CH_3 \xrightarrow{\text{slow}} CH_3-\underset{+}{\overset{CH_3}{C}}-CH_3 + H_2O$$

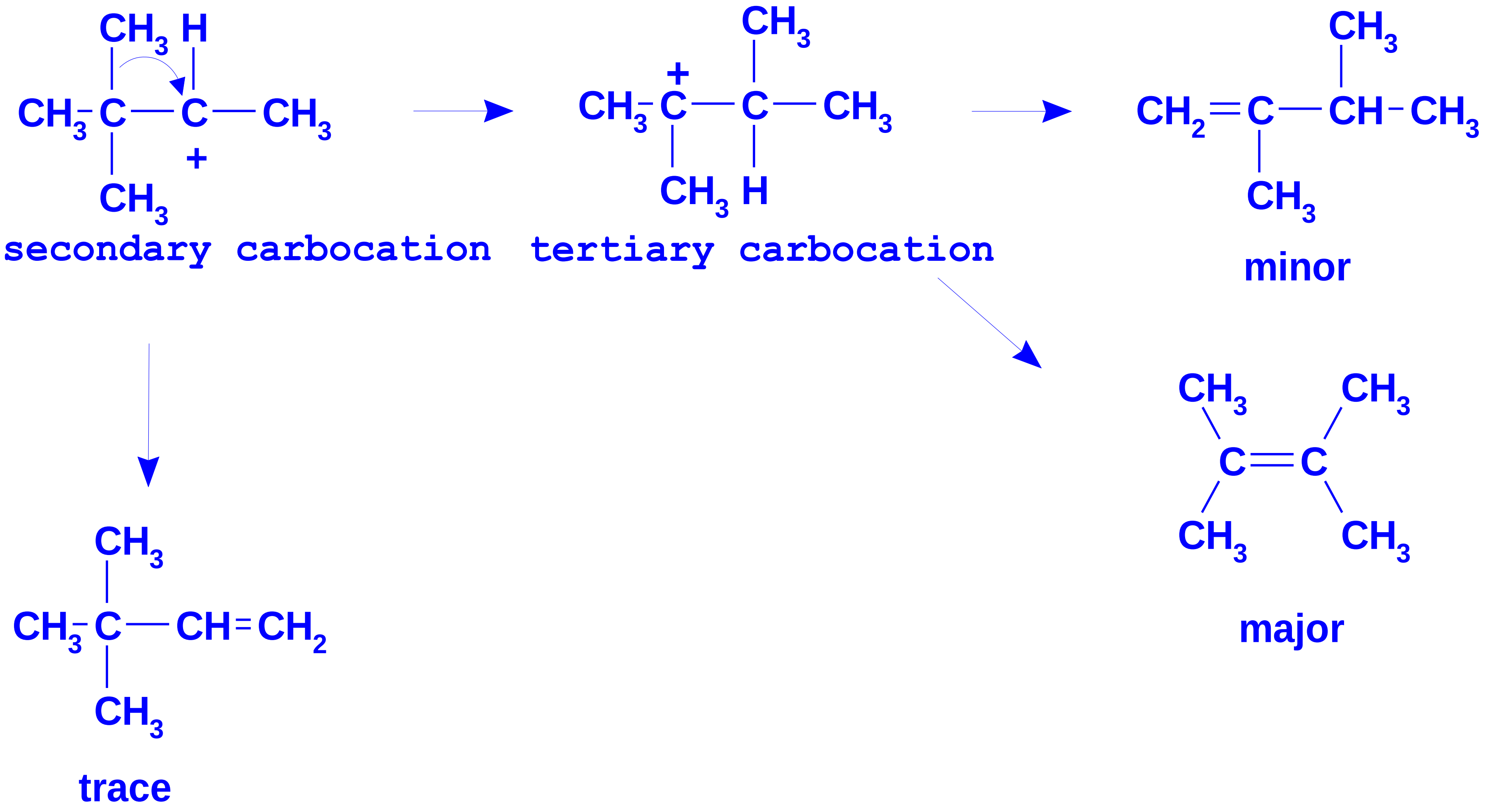
3) $$CH_3-\underset{+}{\overset{CH_3}{C}}-CH_3 \longrightarrow (CH_3)_2C=CH_2 + H^+$$

Sect 9.7: rearrangements in dehydration reactions



secondary carbocation

Sect 9.7: rearrangements in dehydration reactions



Rearrangements

- Alkyl groups and hydrogen can migrate in rearrangement reactions to give more stable intermediate carbocations.
- You shouldn’t assume that rearrangements always occur in all E1 reactions, otherwise paranoia will set in!!

Sect 9.8: comparison of E2 / E1

- E1 reactions occur under essentially neutral conditions with *polar solvents,* such as water, ethyl alcohol or acetic acid*.*
- E1 reactions can also occur with strong bases, but only at *low concentration*, about 0.01 to 0.1 M or below.
- E2 reactions require strong base in *high concentration*, about 1 M or above.

Sect 9.8: comparison of E2 / E1

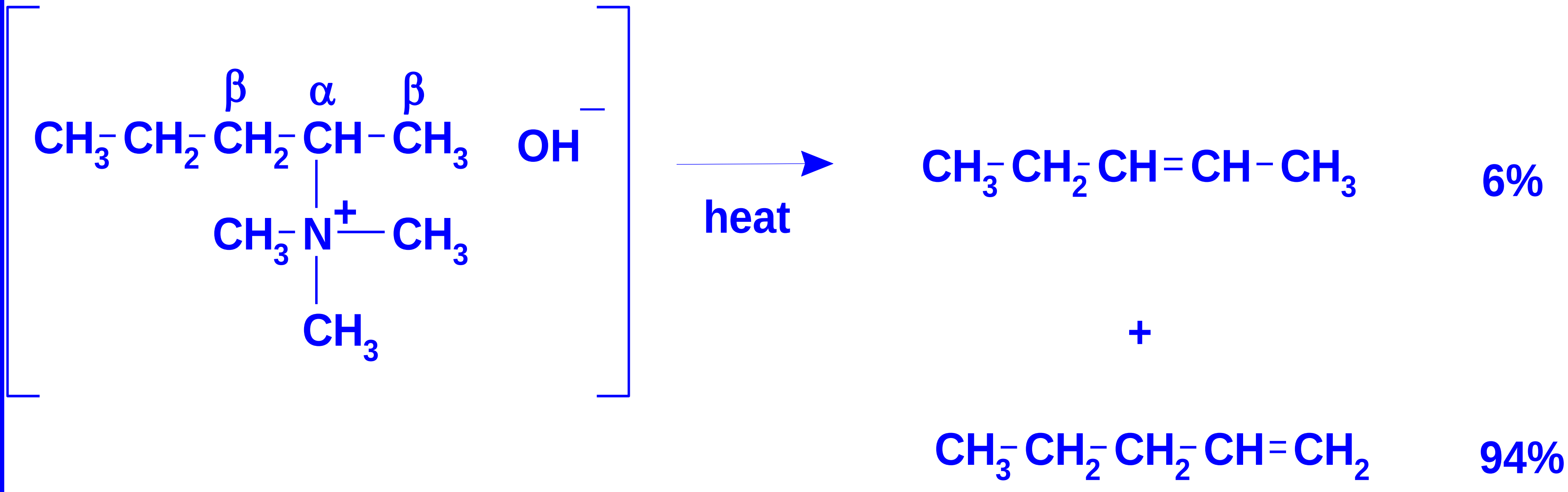
- E1 is a stepwise mechanism (two or more);

  Carbocation intermediate!
- E2 is a concerted mechanism (one step)

  No intermediate!
- E1 reactions may give rearranged products
- E2 reactions don’t give rearrangement
- Alcohol dehydration reactions are E1

Sect 9.9: bulky leaving groups -- Hofmann Elimination

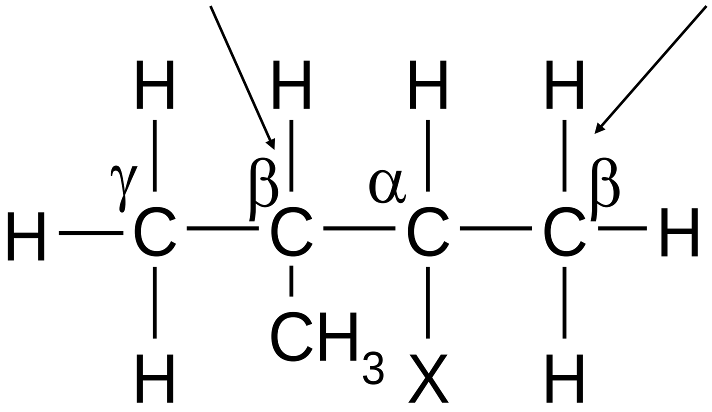
This give the *anti*-Zaitsev product (least substituted product is formed)!



$$\left[\; CH_3-CH_2-\overset{\beta}{CH_2}-\overset{\alpha}{CH}\big(\overset{+}{N}(CH_3)_3\big)-\overset{\beta}{CH_3} \quad OH^- \;\right] \xrightarrow[\text{heat}]{} CH_3-CH_2-CH=CH-CH_3 \;\; 6\% \;+\; CH_3-CH_2-CH_2-CH=CH_2 \;\; 94\%$$

Orientation of elimination: regiochemistry/ Hofmann’s Rule

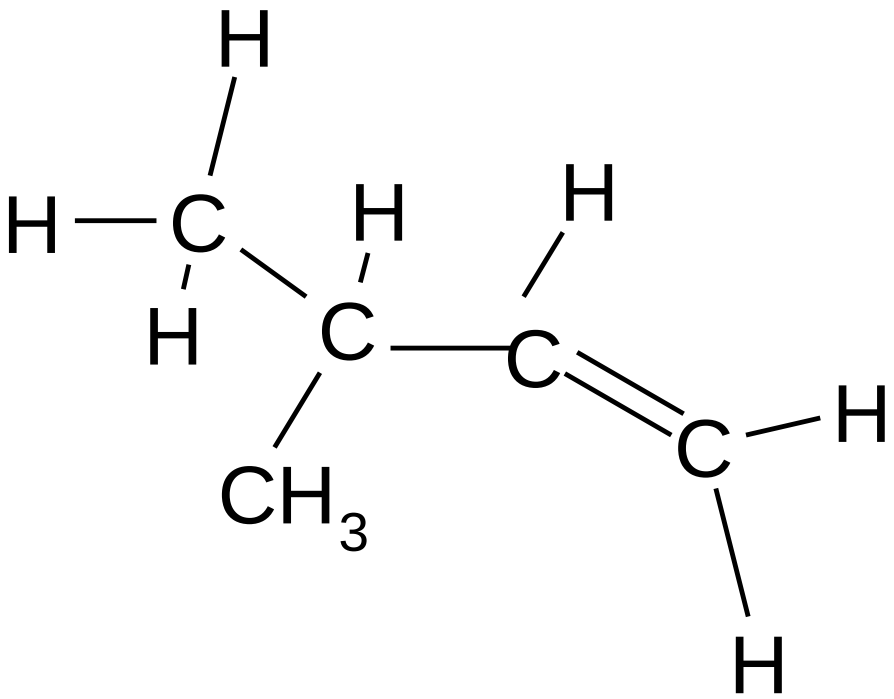
- In bimolecular elimination reactions in the presence of either a bulky leaving group or a bulky base, the *hydrogen* that is lost will come from the ***LEAST*** *highly-branched* β-carbon.



More branched

Less branched

Product from previous slide

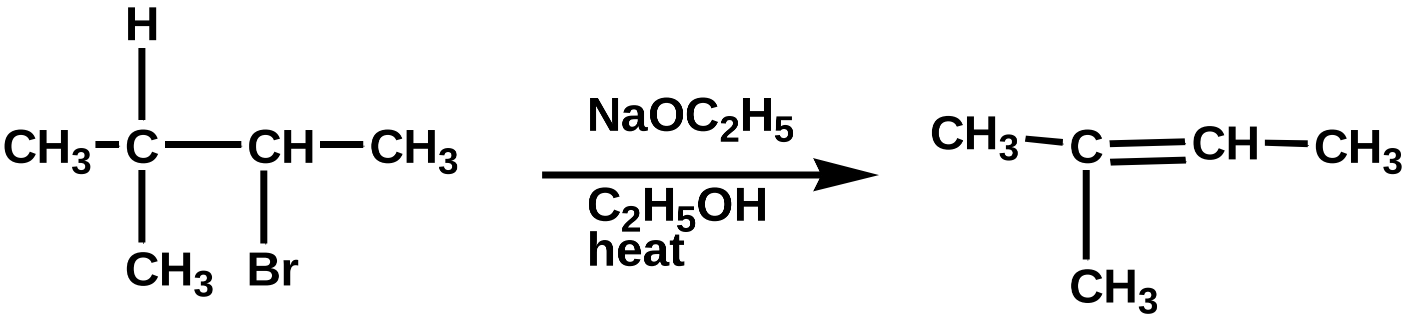


Sect 9.10 Elimination with bulky bases

- Non-bulky bases, such as hydroxide and ethoxide, give Zaitsev products.

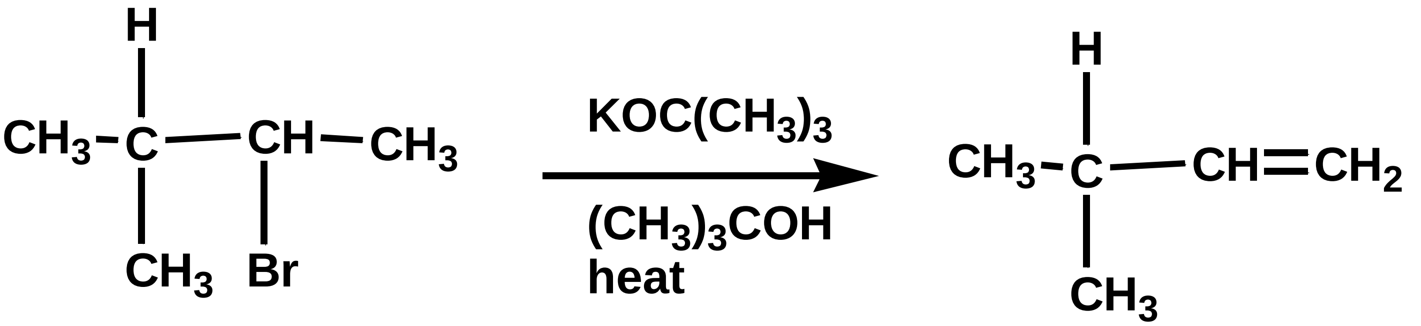
- Bulky bases, such as potassium *tert*-butoxide, give larger amounts of the *least* substituted alkene (Hoffmann) than with simple bases.

Comparing Ordinary and Bulky Bases



$$CH_3-\overset{H}{\underset{CH_3}{C}}-\underset{Br}{CH}-CH_3 \xrightarrow[C_2H_5OH\ \text{heat}]{NaOC_2H_5} CH_3-\underset{CH_3}{C}=CH-CH_3$$

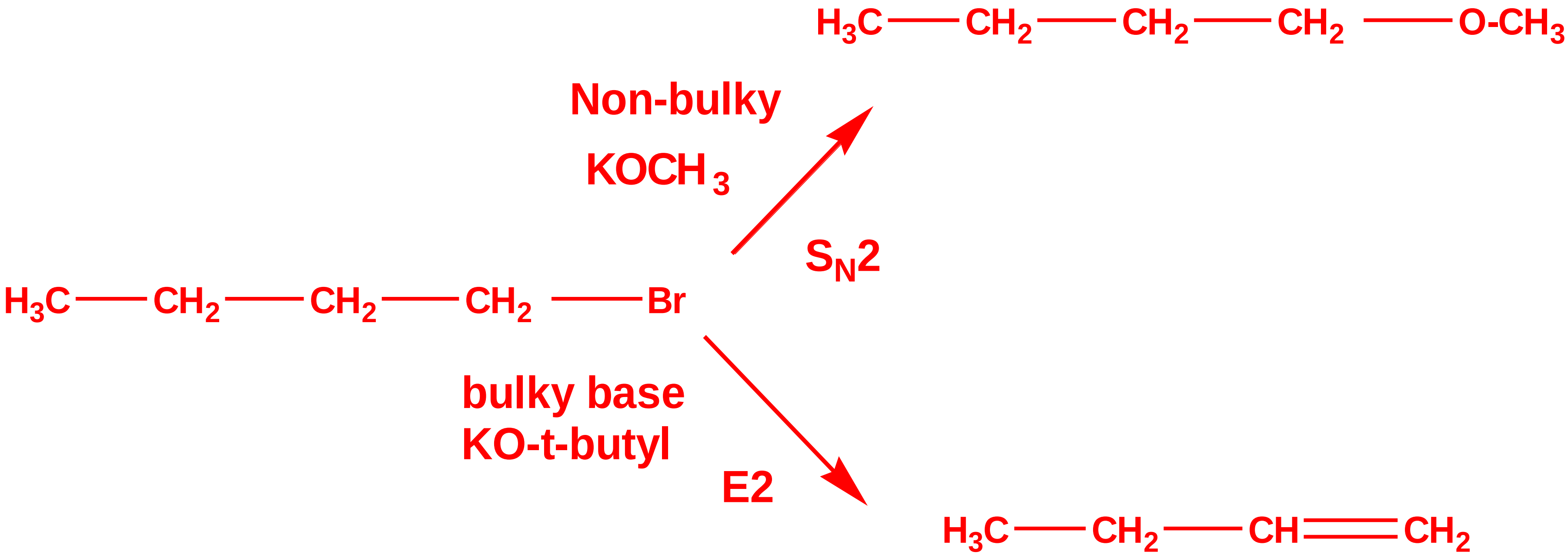
Major



$$CH_3-\overset{H}{\underset{CH_3}{C}}-\underset{Br}{CH}-CH_3 \xrightarrow[(CH_3)_3COH\ \text{heat}]{KOC(CH_3)_3} CH_3-\overset{H}{\underset{CH_3}{C}}-CH=CH_2$$

Major

1-butene: watch out for competing reactions!



$H_3C-CH_2-CH_2-CH_2-Br$

Non-bulky

$KOCH_3$

S_N2

$H_3C-CH_2-CH_2-CH_2-O\text{-}CH_3$

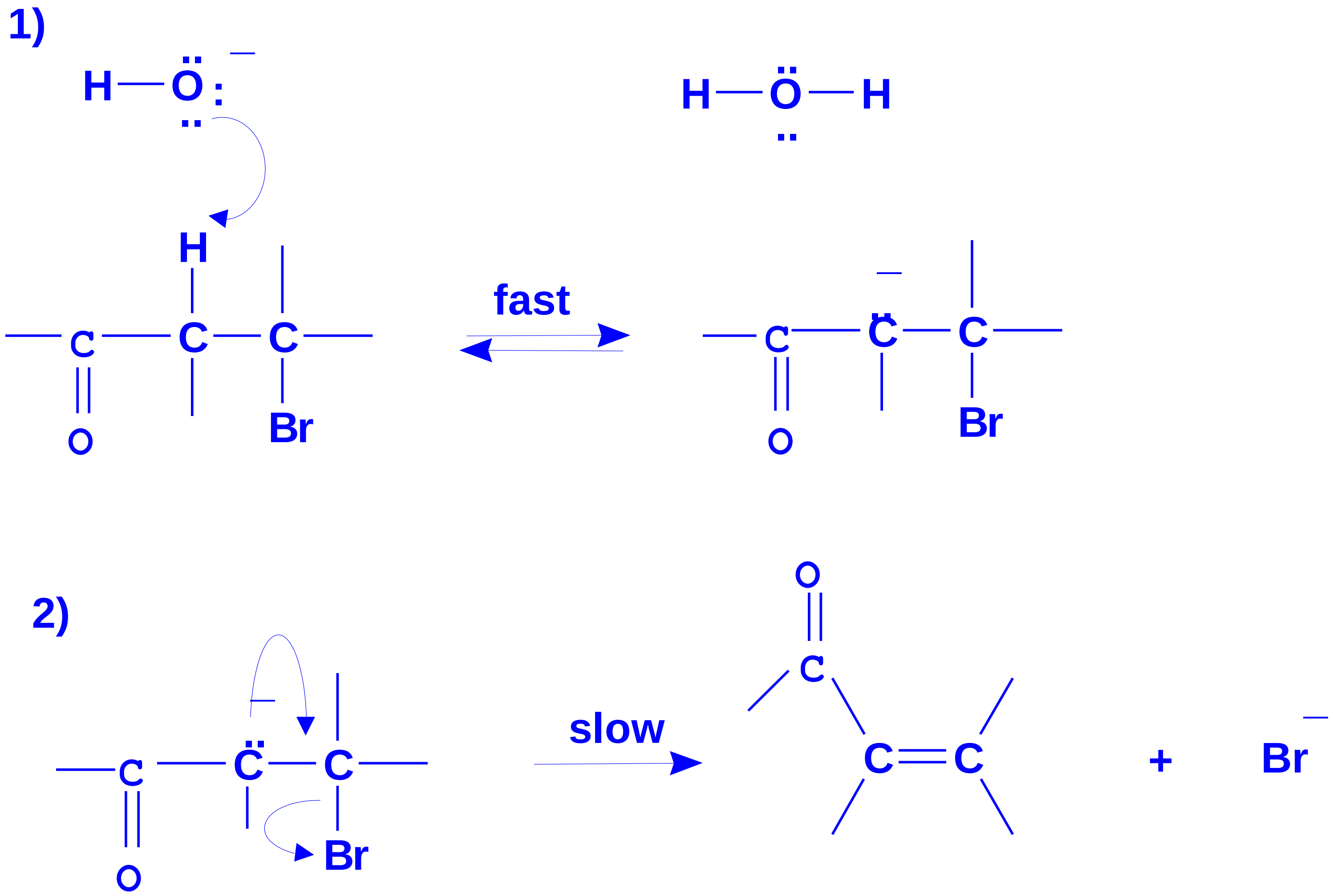
bulky base

KO-t-butyl

E2

$H_3C-CH_2-CH=CH_2$

Sect 9.11 the E1cb mechanism:

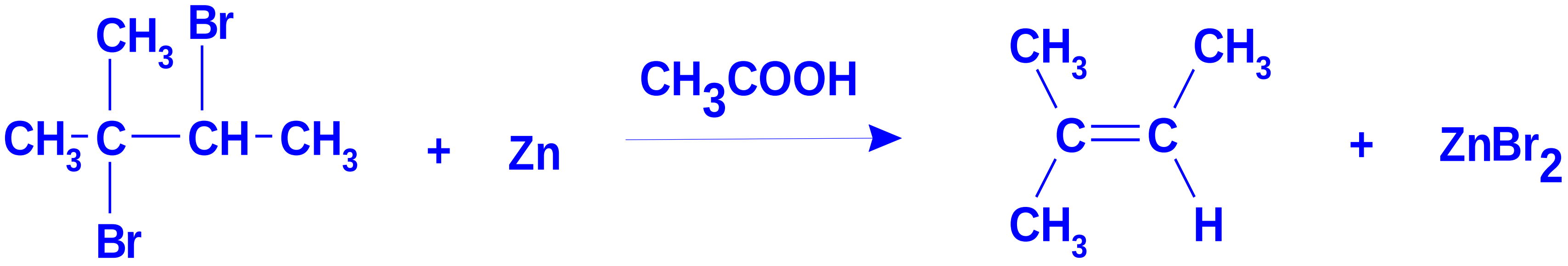


Sect 9.13 alpha-Elimination Reactions

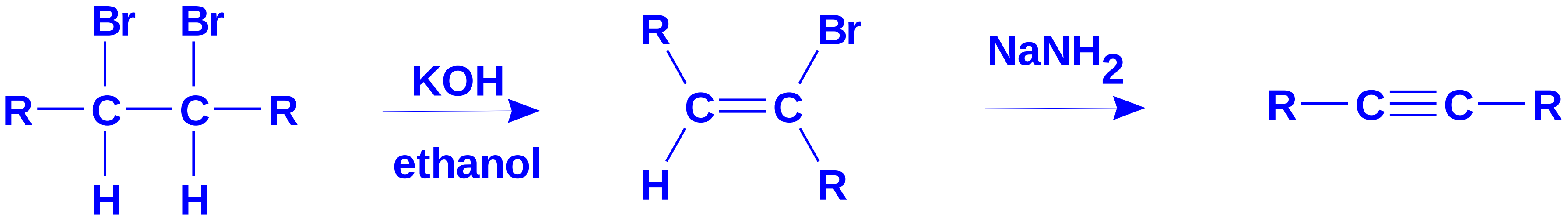
- These unusual reactions occur with one carbon compounds, only.
- Examples include chloroform and methylene chloride.
- Cyclopropane compounds are formed.

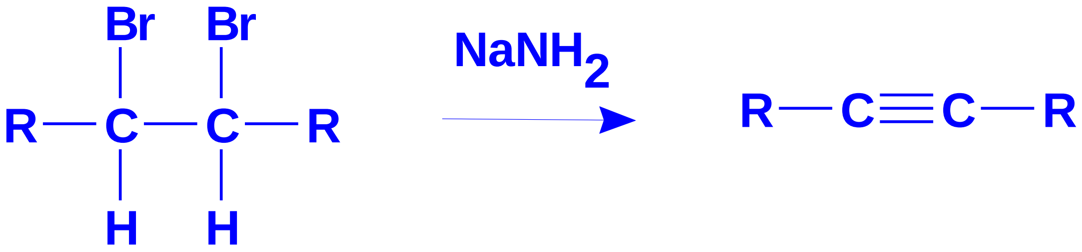
Sect 9.14: Dehalogenation: skip Summer 2006

This reaction requires the two Br's to be *anti.*



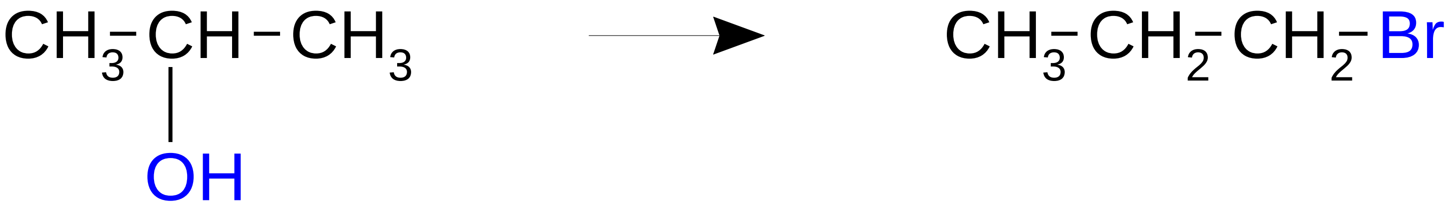
Sect 9.15: Preparation of Alkynes -- double dehydrohalogenation





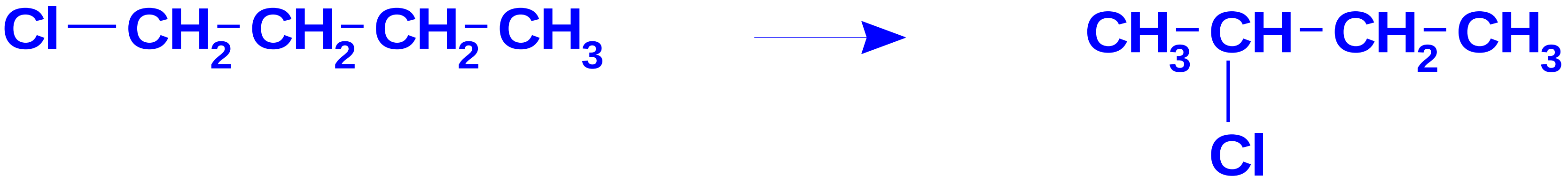
Sect. 9.16: Multistep reactions and Synthesis -- Example 1

Synthesis: Example 1



$$CH_3-\underset{OH}{\underset{|}{CH}}-CH_3 \longrightarrow CH_3-CH_2-CH_2-Br$$

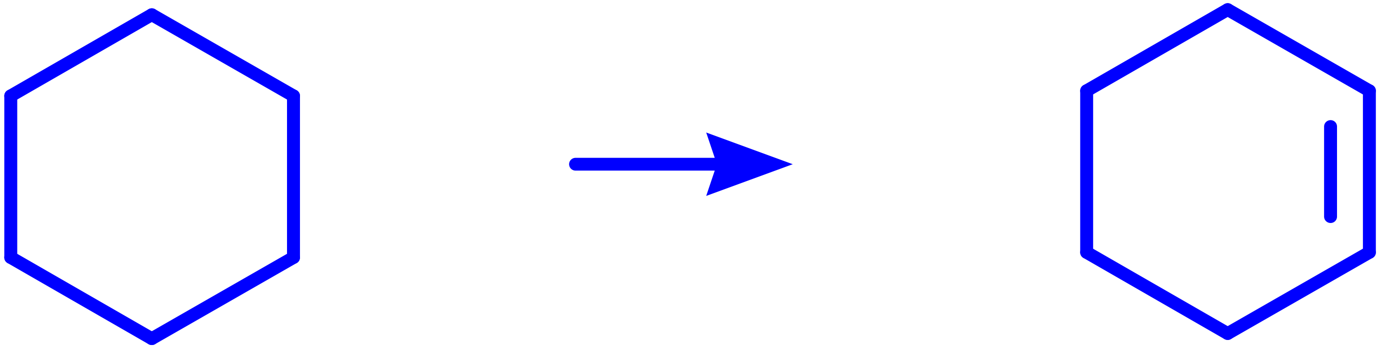
Multistep reactions and Synthesis
Example 2



$$Cl-CH_2-CH_2-CH_2-CH_3 \longrightarrow CH_3-\underset{\displaystyle Cl}{\underset{|}{CH}}-CH_2-CH_3$$

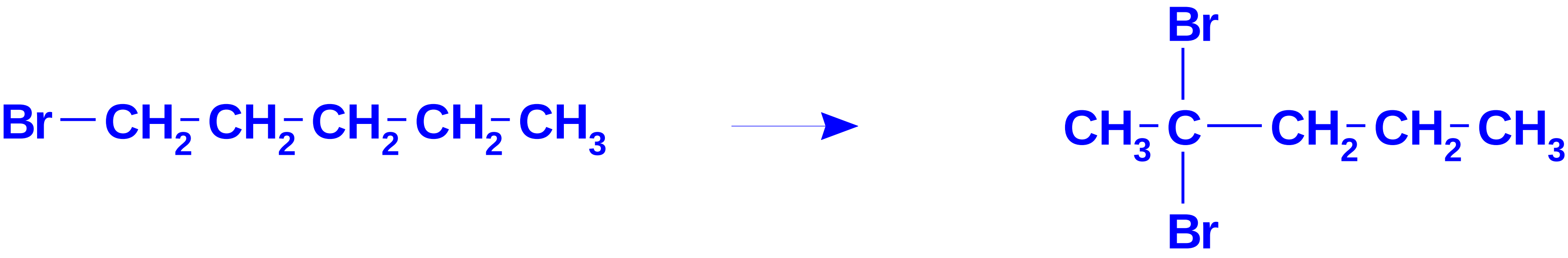
Multistep reactions and Synthesis

Example 3



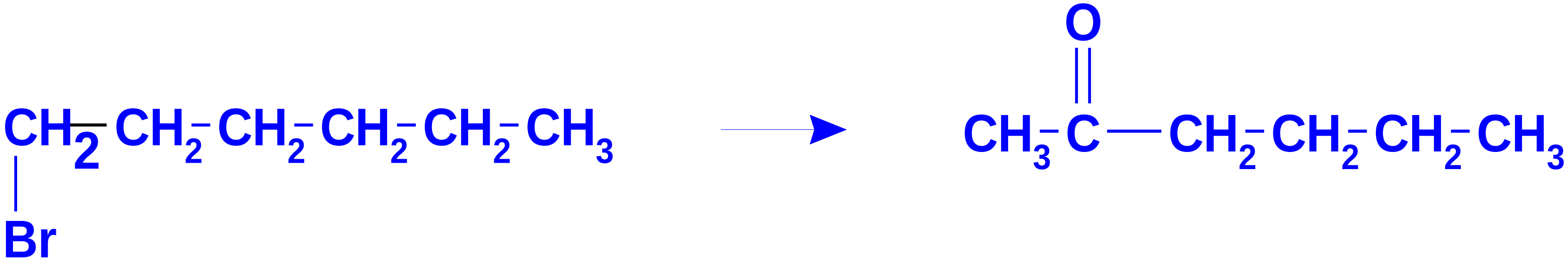
Multistep reactions and Synthesis

Example 4



$$Br{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}CH_3 \longrightarrow CH_3{-}\overset{\displaystyle Br}{\underset{\displaystyle Br}{C}}{-}CH_2{-}CH_2{-}CH_3$$

Synthesis: Example 5



$$\underset{\displaystyle Br}{CH_2}-CH_2-CH_2-CH_2-CH_2-CH_3 \longrightarrow CH_3-\overset{\displaystyle O}{\overset{\|}{C}}-CH_2-CH_2-CH_2-CH_3$$

Highlights of Chapter Nine

- Dehydrohalogenation -- E2 Mechanism
- Zaitsev’s Rule
- Isotope Effects
- Dehydrohalogenation -- E1 Mechanism
- Dehydration of Alcohols -- E1
- Carbocation Rearrangements -- E1
- Elimination with Bulky Leaving Groups and Bulky Bases -- Hofmann Rule -- E2
- Multistep Reactions and Synthesis